Polluted Groundwater

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A Review of the Significant Literature

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This printing has been undertaken to make this excellent report available in a conventional format for general and reference use.

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Preface

The current concern for control of water pollution and for the maintenance of high quality water supplies has stimulated an interest in the pollution of groundwater. This volume contains a selective review of the literature on man-caused groundwater pollution, including causes, occurrences, procedures for control, and methods for monitoring. We have made no attempt to develop a comprehensive bibliography on the subject; references were selected for inclusion on the basis of their significance and relevance.

Bibliographies and important general references are discussed separately. Thereafter the literature is described in essay form on a subject basis. References cited by number in the text are listed in complete bibliographic form at the end of the book together with an author index. With few exceptions, the material reviewed is limited to relatively recent published items in the United States. Administrative regulations, legal reports, and unpublished materials such as theses have been omitted.

The material in this book was originally prepared for the U. S. Environmental Protection Agency as part of a contractual study by TEMPO, the Center for Advanced Studies of the General Electric Company. Mr. Charles F. Meyer of General Electric-TEMPO and Mr. Leslie G. McMillion of the Environmental Protection Agency provided technical guidance during the course of the study. We are pleased to acknowledge their assistance as well as their encouragement to publish this work in book form. Finally, we wish to acknowledge the extensive use made of the libraries of the University of California, Berkeley, and particularly of the Water Resources Center Archives.

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CHAPTER I

INTRODUCTION

This review is concerned with groundwater pollution resulting from activities of man. Natural groundwater, unaffected by man, contains salts in solution with the concentration depending upon the previous history of the water and upon geologic and hydrologic influences. Current governmental endeavors are focused on modifying the consequences of man's activities so as to prevent, reduce, and eliminate groundwater pollution, and to restore and maintain the integrity of the Nation's groundwaters.

Literature included herein was selected on the basis of its significance and relevance from a variety of bibliographies, general references, and abstracts. Where an abstract was not available to judge the value of the reference, the original reference was consulted to determine its pertinence. In some cases, only the title of a reference could be located in available libraries and within the time constraints of the study. Where the title appeared to so warrant, the reference was included at the end of the "References" list (numbers 596 to 661) but was not discussed in the text.

Excluded from consideration were all unpublished materials, administrative regulations at all governmental levels, and legal reports. The study has been limited to the literature of the United States, with the exception of a few Canadian reports and a recent book on the European groundwater pollution situation. Items of historical interest have also been excluded because they have limited bearing on the current and future pollution situation; only a few references predate 1950.

In the area of research reports, selections were restricted to those directly concerning changes in groundwater quality. Numerous works which indirectly relate to the subject, including flow and mixing phenomena in porous media, infiltration and clogging rates, adsorptive and ion exchange properties of soils, etc., were excluded.

Chapters II and III contain annotated listings of bibliographies and important general references. Thereafter, the literature is reviewed in essay form on a subject basis.

Seven subject headings are covered in Chapters IV to X. Under each of these, several subsections review literature on a given topic. Each of the 595 references reviewed is classified under one of the 30 topical headings. Many papers and reports embrace more than one subject; these have been assigned to the section which seemed most appropriate. Consequently, in using this review a reader is advised to consider closely related topics which may contain reviews that prove pertinent to his particular interest. Note also the "General" category in Chapter IX, which contains references on all facets of groundwater pollution.

At the end of the report all references cited by number are listed in complete bibliographic form, in the order mentioned in the text. Finally, an author index of all references is included to facilitate location of particular materials.

CHAPTER II

BIBLIOGRAPHIES

The following recently published bibliographies are closely related to the subject of groundwater pollution. Annotations describe the scope and extent of material included in each bibliography.

(A) Rima, D. R., E. B. Chase, and B. M. Myers. *Subsurface Waste Disposal by Means of Wells–A Selective Annotated Bibliography.* Water-Supply Paper 2020. U.S. Geological Survey, Washington, D. C., 1971, 305p.

A total of 692 references with abstracts covering source materials through 1969 are included. The references are about equally divided among three topics: disposal of oil-field brines, research on disposal of radioactive wastes, and case histories of industrial injection wells. Abstracts are arranged alphabetically by author. Geographic and subject indexes conclude the bibliography.

(B) *Subsurface Water Pollution–A Selective Annotated Bibliography,* Pt. I–Subsurface Waste Injection, Pt. II–Saline Water Intrusion, Pt. III–Percolation from Surface Sources. U.S. Environmental Protection Agency, Washington, D. C., March 1972, 156p., 161p., 162p.

These three volumes contain a total of 319 references; all are directly related to groundwater pollution. References include abstracts and are arranged according to WRSIC accession numbers. Each part of the bibliography includes a significant descriptor index and a comprehensive subject index.

(C) *Subsurface Water Pollution by Percolation–Selected Abstracts.* National Technical Information Service. Springfield, Virginia. Rept. NTIS-PK-134. November 1972. 35p.

This listing contains 35 references with abstracts and descriptors.

(D) Bader, J. S., and others. *Selected References–Ground-Water Contamination, The United States of America and Puerto Rico.* U.S. Geological Survey, Washington, D. C., 1973, 103p.

This contains 834 references without abstracts. Numerous cooperative area investigations by the U.S. Geological Survey are

listed alphabetically by author. Particularly valuable are indexes according to geographic areas, states, kinds of contamination, sources of contamination, and general discussions.

(E) Summers, W. K., and Z. Spiegel. *Ground Water Pollution, A Bibliography.* Ann Arbor Science Publishers, Ann Arbor, Michigan, 1974, 83p.

More than 400 partially annotated references are listed in this bibliography. The material is organized on a subject basis under 12 chapter headings. The references concentrate on nitrates, heavy metals, and pesticides as well as on effects of urbanization, solid waste disposal, animal wastes, and petroleum products.

(F) WRSIC Bibliographies. In 1971 the Water Resources Scientific Information Center began publication of a series of bibliographies in water resources produced from the extensive information base comprising *Selected Water Resources Abstracts.*

Each bibliography includes a significant descriptor index, a comprehensive subject index, and an author index. References include abstracts and are arranged according to WRSIC accession numbers. The following bibliographies have been selected as being those which may or do contain references pertaining to groundwater pollution. The three bibliographies listed under the heading *Subsurface Water Pollution* are identical to those described in (B) above. For identification purposes the WRSIC numbers follow the titles. The PB numbers indicate availability from the National Technical Information Service.

Strontium in Water	WRSIC 71-201	PB 201268
Arsenic and Lead in Water	WRSIC 71-209	PB 202578
DDT in Water	WRSIC 71-211	PB 212262
Detergents in Water	WRSIC 71-214	PB 206527
Dieldrin In Water	WRSIC 72-202	PB 207339
Aldrin and Endrin in Water	WRSIC 72-203	PB 210922
Chromium in Water	WRSIC 72-205	PB 210921
Mercury in Water	WRSIC 72-207	PB 206535
Soil Nitrogen Cycle	WRSIC 72-208	PB 209931
Sanitary Landfills	WRSIC 72-214	PB 211565
Subsurface Water Pollution		
I. *Subsurface Waste Injection*	WRSIC 72-220E	PB 211340
II. *Saline Water Intrusion*	WRSIC 72-221E	PB 211341

III. *Percolation from Surface Sources*	WRSIC 72-222E	PB 211342
PCB in Water	WRSIC 73-201	PB 217859
Artificial Recharge of Groundwater	WRSIC 73-202	PB 221479
Cadmium in Water	WRSIC 73-209	PB 218829
Water Reuse, Volume 1	WRSIC 73-215	PB 221998
Water Reuse, Volume 2	WRSIC 73-215	PB 221999
Phosphorus Removal, Volume 1	WRSIC 73-208	PB 221477
Phosphorus Removal, Volume 2	WRSIC 73-208	PB 221478
Acid Mine Water	WRSIC 75-202	
Water Reuse, Volume 3	WRSIC 75-204	
Water Reuse, Volume 4	WRSIC 75-204	

CHAPTER III

IMPORTANT GENERAL REFERENCES

Among the numerous references relating to groundwater pollution, a few view the subject broadly and comprehensively. Because such general references are important for persons wishing to obtain an introduction to the subject, these publications have been specially listed and described below.

(A) *Ground Water Contamination, Proceedings of the 1961 Symposium.* Public Health Service, U.S. Department of Health, Education, and Welfare. Tech. Rept. W61-5. 1961. 218 p.

This report summarizes papers and discussions of a Public Health Service symposium on groundwater contamination. A total of 38 papers were presented, organized around five topics: (1) Hydrogeological aspects of groundwater contamination, (2) Types of contaminants, (3) Specific incidents of contaminants in groundwater, (4) Regulations and their administration, and (5) Research on groundwater contamination. Some 192 references are included. This is the earliest comprehensive analysis of the many facets of groundwater pollution.

(B) Ballentine, R. K., S. R. Reznek, and C. W. Hall. *Subsurface Pollution Problems in the United States.* U.S. Environmental Protection Agency. Washington, D. C. Tech Studies Rept. TS-00-72-02. May 1972. 29 p.

A general discussion of the subject is presented under the headings of deep well injection, percolation from surface sources, salt water intrusion, and controls.

(C) Fuhriman, D. K., and J. R. Barton. *Ground Water Pollution in Arizona, California, Nevada, and Utah.* Fuhriman, Barton and Assocs. Washington, D. C. Water Pollution Research Series Rept. 16060 ERU 12/71. U.S. Environmental Protection Agency. December 1971. 249 p.

This report covers groundwater pollution problems in Arizona, California, Nevada, and Utah. Natural mineralization is mentioned as the most important influence on groundwater quality. Significant man-caused effects include irrigation return flows, sea water intrusion, solid wastes, and disposal of oil field

brines. Research needs to control pollution are discussed. The report includes a list of 241 references, a glossary of terms, a summary of water quality standards for various water uses, and a bibliography of 1132 items.

(D) Scalf, M. R., J. W. Keeley, and C. J. LaFevers. *Ground Water Pollution in the South Central States.* U.S. Environment Protection Agency. Corvallis, Oregon. Rept. EPA-R2-73-268. June 1973. 181 p.

This report describes present and potential groundwater pollution problems of Arkansas, Louisiana, New Mexico, Oklahoma, and Texas. Mineralization due to natural causes is listed as the most influential factor on groundwater quality, while oil field activities constitute the greatest man-made cause. Research needs to solve problems associated with various causes of underground pollution are enumerated. The report includes a list of 132 references, a glossary of terms, a summary of water quality standards for various water uses, and a bibliography of 385 items.

(E) *Ground-Water Contamination–An Explanation of Its Causes and Effects.* Geraghty & Miller, Inc. Port Washington, N.Y. May 1972. 15 p.

This pamphlet gives a general description of groundwater pollution. Included are causes and types of contamination, geologic influences and the movement of pollutants, governmental regulation, and investigations for control. A suggested reading list of 33 items concludes the report.

(F) Pettyjohn, W. A. (editor). *Water Quality in a Stressed Environment.* Minneapolis, Minn., Burgess, 1973. 309 p.

This book consists of a collection of previously published papers on water pollution. Geologic controls associated with groundwater pollution are the subject of five papers, while seven others describe examples of groundwater pollution. Included in the examples are reports on pollution from industrial plants, chemical plants, oil field brines, sewage lagoons, horse stables, septic tanks, and bacteria and viruses.

(G) Campbell, M. D., and J. H. Lehr. Ground Water Pollution. In: *Water Well Technology.* New York, N.Y., McGraw-Hill, 1973. p. 11-28.

This chapter gives a brief review of the causes of groundwater pollution with emphasis on effects of wells. A list of 32 references is included.

(H) Meyer, C. F. (editor). *Polluted Groundwater: Some Causes, Effects, Controls, and Monitoring.* General Electric Company. Santa Barbara, Calif. Rept. EPA-600/4-73-001b. U.S. Environmental Protection Agency. July 1973. 264 p.

This comprehensive report describes methods for controlling groundwater pollution resulting from injection wells into saline water and freshwater aquifers; land disposal and septic systems; sewer, tank, and pipeline leakage; surface waters, the atmosphere, and urban areas; salt water intrusion in coastal and inland aquifers; and spills and artificial recharge. In addition, for each causal factor the environmental consequences, pollution movement, and monitoring procedures are discussed. The report includes 33 figures, 29 tables, and 256 references.

(I) WPCF Research Committee. 1972 Water Pollution Control Literature Review–Effects on Groundwater. *Jour. Water Pollution Control Federation. 45:* 1296-1301, June 1973.

This annual review (which appears in each June issue) summarizes briefly the recent groundwater pollution literature. A total of 30 references are discussed, almost all having appeared in 1972. (It should be noted that other sections of the review may also contain pertinent material: continuous monitoring, automated analysis, and sampling procedures; lagoons and oxidation ponds; detergents; water reclamation and reuse; deep-well injection; agricultural wastes; solid wastes and water quality; and radioactive wastes.)

(J) Miller, D. W., F. A. DeLuca, and T. L. Tessier. *Ground Water Contamination in the Northeast States.* U.S. Environmental Protection Agency. Ada, Oklahoma. Rept. EPA-660/2-74-056. June 1974. 325 p.

This report evaluates the principal sources of groundwater pollution in the 11 northeast states, including all of New England, New York, New Jersey, Pennsylvania, Maryland, and Delaware. Principal sources of quality degradation include septic tanks, buried tanks and pipelines including sewers, highway deicing salts, and landfills. The report includes a list of 403 references, a glossary of terms, and a summary of drinking water standards.

(K) Cole, J. A. (editor). *Groundwater Pollution in Europe.* Proceedings of a Conference organized by the Water Research Association in Reading, England, September 1972. Port Washington, N. Y., Water Information Center, 1974. 547 p.

This comprehensive volume contains some 52 papers and case histories concerning all aspects of groundwater pollution in Europe. The subject matter is organized under the following topical headings: legal and administrative measures, hydrogeology and hydraulics, chemistry, microbiology, case histories, tracers, and deep well disposal. An extensive bibliography and a subject index complete the book.

CHAPTER IV

URBAN POLLUTION

EFFLUENT RECHARGE

Effluent from municipal wastewater treatment plants often is discharged into surface waters. However, in some instances the treated water is reclaimed by percolating it into the ground to recharge aquifers. The groundwater pollution possibilities inherent in water reclamation by artificial recharge projects have been explored frequently.[1-9] In 1955 the University of California Sanitary Engineering Research Laboratory[1] gathered and evaluated pertinent studies, and reviewed methods and statistics of recharge by effluent spreading and injection. Data on infiltration rates and pollution travel were cited, along with the engineering and economic aspects involved.

In 1968 Popkin and Bendixen[2] summarized studies on the application of liquid waste to the soil, in which continuing hydraulic acceptance and percolate quality were stressed. Results suggested that design and operation of a soil adsorption system could be improved by weekly dosing and/or by use of improved pretreatment processes.

Tchobanoglous and Eliassen[3] in 1969 discussed various factors related to the indirect cycle of water reuse. Methods of treated wastewater recharge were surface spreading, direct injection, and pits and leach field seepage. Recharge operations required consideration of the rate, quality, and quantity of wastewater application; site characteristics; and available treatment processes. Finally, a cost-benefit analysis for economic feasibility of indirect reuse of reclaimed water was outlined.

In 1969 Bouwer[4] described how aerobic percolation and subsequent lateral movement of low quality water could remove biodegradable materials, pathogenic organisms, and certain inorganic substances. With respect to problems of recharge basin management, the report warned against allowing accumulation of suspended materials on the basin bottom and against insufficient oxygen reaching the soil during dryups. Basins also needed to avoid excessive water table buildup while achieving maximum recharge per

unit area. Nitrate reduction by denitrification was identified as a major problem in renovating sewage effluent.

The geohydrology of liquid waste disposal by irrigation was reviewed by Born and Stephenson[5] in 1969. The thickness, nature, and distribution of unconsolidated surface deposits determined infiltration, adsorption storage, and downward movement of wastewater. The uses of infiltrometer tests, laboratory examinations, and flow systems were explained as methods of monitoring wastewater recharge.

Additional monitoring and control methods were analyzed by Martin[6] in 1969. The importance of soil surveys in minimizing leaching, erosion, and groundwater contamination was stressed, and a Minnesota soil survey was included. Nitrogen contamination problems could be controlled by anaerobic conditions, plant growth, holding lagoons, and rotation spreading. In addition, several successful land waste disposal systems were described.

Dvoracek and Wheaton[7] in 1970 presented various localized examples of groundwater contamination by artificial recharge due to poor quality recharge water. Various methods of recharge were described (including wells, shafts, holes, pits, trenches, spreading, and "clean" nuclear explosions), and the contamination potential of each was discussed.

More recently, in 1972 and 1973, planning and design criteria for specific waste disposal methods have been presented. The Pennsylvania Bureau of Water Quality Management[8] published a manual on spray irrigation methods and designs. The design and engineering aspects of a proposed operation, site selection criteria, and essential groundwater quality monitoring data were all detailed.

Similarly, Bernhart[9] analyzed various soil infiltration and evapotranspiration methods of wastewater disposal. Project design and area calculations for seepage beds were included, and the effectiveness of septic tanks, aeration tanks, conventional tile fields, and seepage beds were charted. The study also considered the "horizontal protective distance" required for water supply wells under various conditions.

More localized studies of effluent recharge and disposal problems and practices have also been done in many states since 1950. Two Pennsylvania State University studies in 1967-68 dealt with the renovation of wastewater effluent by irrigation of forest land. Pennypacker, et al.[10] conducted a field study of treated sewage effluent sprayed on forest land, and found that while ABS and phosphorus were removed in the top soil layers, greater depths were re-